

# Strategies for controlling pollution from vehicular emissions in Beijing

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**Sammendrag:** Denne artikkelen beskriver det alvorlige problemet med forurensing fra biltrafikken i Beijing, og diskuterer følgende strategier for å redusere utslippene: forbedre drivstoffkvaliteten, krav til maksimale utslipp fra nye kjøretøy, krav til maksimale utslipp fra biler i bruk, for eksempel ved kontroll og vedlikehold, oppgradering av bruktbiler, vraking av gamle biler, og infrastruktur- og trafikktiltak.

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**Abstract:** This paper describes the severe situation of vehicular emission pollution in Beijing, and discusses the following mitigation strategies: improving fuel quality, controlling the exhaust from new vehicles, controlling the emissions from vehicles in use through, e.g., Inspection/Maintenance (I/M), renovating in-use vehicles and scrapping of old vehicles, and road infrastructure and traffic policies.

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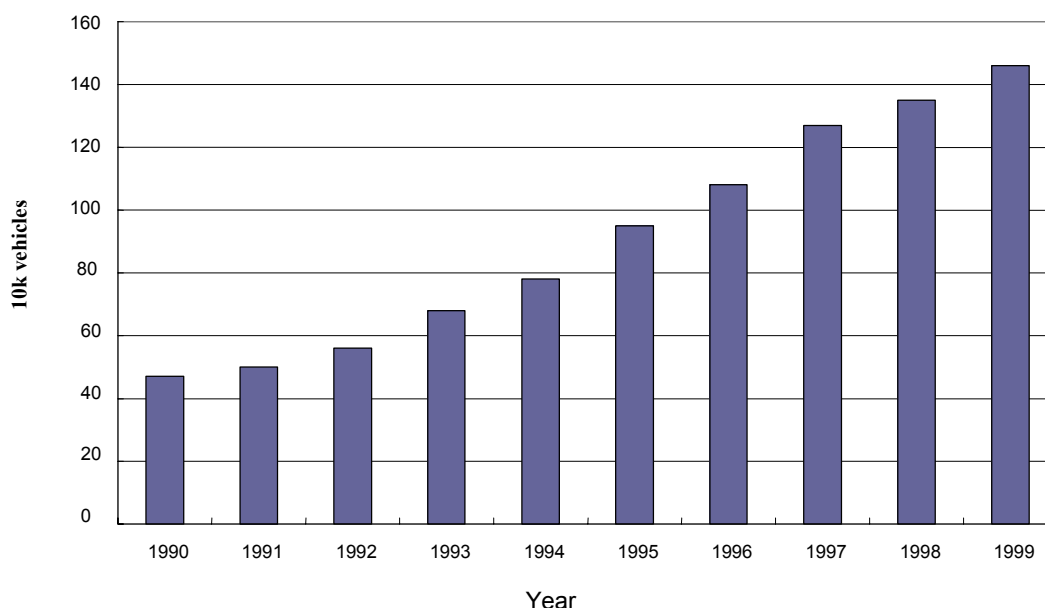
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## 1 Introduction

In recent years, concentrations of sulfur dioxide (SO<sub>2</sub>) and total suspended particulates (TSP) in the air of urban and suburban Beijing have remained stable. But, motor vehicles are becoming the major source of air pollutant emissions. During the 1990s, the average growth rate in Beijing was as high as 17.4%<sup>[1]</sup>. At the end of 1997, the vehicle number in Beijing was 1.27 million, in 1998 1.37 million, in 1999 reached 1.46 million and at the end of 2002, it will be 2 million. Figure 1 shows the growth in the vehicle population in Beijing from 1990 to 1999.



**Figure 1. Growth in the vehicle population in Beijing**<sup>[2]</sup>

As a result of the rapid growth in the vehicle population, absolute emissions, the vehicular emission contribution rate, and the concentration contribution rate showed a significant increase (see Table 1).

**Table 1. Vehicular emissions and their contribution rate in Beijing**

		1995			1998		
Contents		Emission (10 <sup>4</sup> t/y)	Emission contribution rate (%)	Concentration contribution rate (%)	Emission (10 <sup>4</sup> t/y)	Emission contribution rate (%)	Concentration contribution rate (%)
Vehicular emission sources	CO	107.51	76.8	76.0	129.00	82.7	84.1
	NO <sub>x</sub>	9.34	40.2	68.0	11.50	42.9	72.8
Settled sources	CO	32.50			27.00		
	NO <sub>x</sub>	14.00			15.30		

Table 1 shows that regardless of the absolute emissions or contribution rate of vehicle exhaust pollutants (CO, NO<sub>x</sub>), the concentration contribution rate is relatively higher than

emission contribution rate. Compared to 1995, the proportion of vehicle pollution increases in 1998.

As the vehicle population in Beijing is expected to continue to increase at a high rate, there is an urgent need to identify existing problems and adopt strategies for controlling vehicular pollution. The remainder of this paper discusses strategies under consideration in Beijing, followed by some general concluding remarks.

## 2 Strict management of fuel types for automobiles

The American Automobile Manufacturers Association (AAMA), Association des Constructeurs Européens d'Automobiles (ACEA), and the Japan Automobile Manufacturers Association (JAMA) proposed the "Worldwide Fuel Charter"<sup>[3]</sup> that was declared in January 1999. In this documentation, gasoline and diesel are divided into four categories: The first category comprises fuels for markets with minimal requirements for emissions control; fuels are considered primarily in terms of fundamental vehicle/engine performance concerns, not emissions. The second category comprises fuels for markets with stringent requirements for emissions control and other market demands – for instance, countries and regions that have carried out Euro I or Euro II regulations. The third category comprises fuels for markets with advanced requirements for emissions control and other market demands – for example, countries and regions that have carried out Euro III or Euro IV regulations. The fourth category comprises fuels for markets with *further* advanced requirements for emissions control and that enable sophisticated NO<sub>x</sub> technologies. Since Beijing adopted the Euro I period regulations in January 1, 1999, its fuel falls into the second category. With respect to further unleaded gasoline requirements and the current situation in Beijing, see Table 2.

**Table 2. Additional requirements for unleaded gasoline and the current situation in Beijing**

Items	requirements	Beijing requirements or fact	note
Octane rating	No.91,95,98	No.90,93,95	No.90 most in the market
Sulfur	<0.02%	0.15%	mass percentage
Lead	0.005g/L	0.013g/L	-
phosphorus	No detecting	No rule	-
manganese	No detecting	No rule	-
Silicon	No detecting	No rule	-
oxygen	<2.7%	No rule	mass percentage
Olefine hydrocarbon	<20%	No rule (30-40%)	volume percentage
aromatic hydrocarbon	<40%	No rule (20-25%)	volume percentage
benzene	<2.5%	No rule (3-4%)	volume percentage
volatility	token as vapor pressure and distillation process	-	-
Other requirements	sediment<1mg/L; colloid<70mg/L	colloid with the same requirements, others no rule	-

In Beijing, it is difficult for the fuel quality to meet newer standards even in China: the sulfur content of gasoline and diesel is relatively high; the olefine hydrocarbon content of gasoline is relatively high; the unleaded gasoline is not really lead-free; and finally, the engine oil contains phosphorus and sulfur.

To address the problems related to automobile fuel, the Beijing government issued regulations and adopted policies to meet national standards for unleaded gasoline. First, the six-month process for phasing out leaded gasoline began in June 1997 and finished in early 1998. Second, the production, distribution, and utilization of automobile fuels were standardized; brands were established, trademarks registered, and the units of production displayed. Third, the quality of inspection of automobile fuel was strengthened.

The fuel components have direct influence on vehicle emissions. Changing the content of some components of gasoline (diesel) results in a change in vehicle emissions. When stricter vehicle emission standards are adopted, fuel then becomes a key factor in the implementation of a comprehensive clean automobile action as long as vehicle emission control technologies remain unchanged.

In general, conforming to newer emission regulations requires both vehicle emission control technologies and corresponding fuel. The petroleum products in China do not meet the new regulation requirements in many aspects; thus, we must consider improving the process of Chinese industry when we establish the implementation timetable of new emission regulations<sup>[4]</sup>.

### **3 Regulating emissions of new vehicles**

In Beijing, five steps were taken to regulate the emissions of new vehicles: the establishment of emissions standards for new vehicles, the approval of new production vehicles emission, market entrance permission, random testing of new vehicles, and the restriction of vehicles being registered in Beijing if they were not originally sold in Beijing.

#### **3.1 Implementation of vehicle and motorcycle emissions standards**

Since 1994, Beijing has issued eleven local vehicles emission regulations. They cover light-duty vehicles, heavy-duty engines, motorcycles and agri-transportation vehicles. Eight of these eleven regulations are related to emissions from new vehicles. On August 25, 1998, the Beijing Environmental Protection Bureau issued "Emission standards for exhaust pollutants from light-duty vehicles" (DB11/105-1998) (equal to EURO I), which was put into effect January 1, 1999. One year later, on July 9, 1999, SEPA issued standards restricting pollutants from exhaust of light vehicles (GWPB1-1999) (equal to EURO I), which took effect from January 1, 2000. It stipulates type approval of light vehicle emission pollutants and emission standard value of production conformity inspection tests and durability requirements for exhaust control devices. Because Beijing is subject to greater pressure to regulate vehicle emissions, it tries to enforce stricter vehicle emissions standards and stay a step ahead of other places in China. Beijing will implement EURO II on Jan. 1, 2003, and plans to carry out EURO III vehicle emission standards in on Jan.1, 2005.

Tables 3 and 4 show pollutants type approval test exhaust standard values for vehicle types I and II.

**Table 3 Type Approval Test Standards of Vehicle Type I (g/km)<sup>[5]</sup>**

Experimental Phase	Pollutants		Exhaust Standards
First Phase: (Jan.1 2000 – June 30 2004)	CO		2.72
	HC+NO <sub>x</sub> <sup>(1)</sup>		0.97 (direct-injection diesel engine 1.36)
	PM <sup>(1)(2)</sup>		0.14 (direct-injection diesel engine 0.20)
Second Phase (start from July 1 2004)	CO	Ignition engine	2.20
		Compression-ignition engine	1.00
	HC+NO <sub>x</sub> <sup>(3)</sup>	Ignition engine	0.50
		Compression-ignition engine	0.70 (direct-injection diesel engine 0.90)
	PM <sup>(3)</sup>	Compression-ignition Engine	0.08 (direct-injection diesel engine 0.10)

Notes:

- (1) The exhaust limit valid time of vehicles using direct-injection diesel engine for driving force listed in the table is 2 years.
- (2) Only applicable for vehicles using compression-ignition engine for driving force.
- (3) The exhaust limit valid time of vehicles using direct-injection diesel engine for driving force listed in the table is 4 years.

**Table 4 Type Approval Test Standards of Vehicle Type II (g/km)**

	Referential Weight (RM), kg		RM≤1250	1250<RM≤1700	RM>1700
First phase (Jan.1 2001 – June 30 2005)	CO		2.72	5.17	6.90
	HC+NO <sub>x</sub> <sup>(1)</sup>		0.97(1.36)	1.40(1.96)	1.70 (2.38)
	PM <sup>(1)(2)</sup>		0.14(0.20)	0.19(0.27)	0.25 (0.35)
Second phase (start from July 1 2005)	CO	Ignition engine	2.20	4.00	5.00
		Compression-ignition engine	1.00	1.25	1.50
	HC+NO <sub>x</sub> <sup>(3)</sup>	Ignition engine	0.50	0.60	0.70
		Compression-ignition engine	0.70(0.90)	1.00(1.30)	1.20(1.60)
	PM <sup>(3)</sup>	Compression-ignition engine	0.08(0.10)	0.12(0.14)	0.17(0.20)

Notes:

- (1) The exhaust limit valid time of vehicles using direct-injection diesel engine for driving force listed in the table is 1 year.
- (2) Only applicable for vehicles using compression-ignition engine for driving force.
- (3) The exhaust limit valid time of vehicles using direct-injection diesel engine for driving force listed in the table is 3 years. Values in brackets are standards for direct-injection diesel engine.

On August 23, 2000, Beijing issued standards regulating motorcycle exhaust pollution (DB 11/120-2000) which is equivalent to EU 97/24/EC and became effective January 1, 2001. (See Table 5.) Other areas in China implement much looser standards, such as GB14621-93.

**Table 5 Beijing Exhaust Pollutants Standards for Motorcycles<sup>[6]</sup>**

Test Conditions	Pollutants	2001.01.01 (2-Stroke)	2001.01.01 (4-Stroke)	2004.01.01
Idle speed Test	CO (%)	1.5	1.5	
	HC (ppm)	3000	300	
Driving Cycle Test	CO (g/km)	4.5	4.5	3.5
	HC + NO <sub>x</sub> (g/km)	3.0	3.0	2.0

### **3.2 Market entrance permission, random testing of new vehicles, and restriction of re-registering vehicles in Beijing**

Beijing implemented EURO I on January 1, 1999, and vehicles (less than 3.5t) that cannot meet the standard may not be sold or registered in Beijing. This means that manufacturers who want to sell vehicles in Beijing sell vehicles that conform to the standards, and can be certified as such, or they will lose the Beijing market. New vehicles, in addition to being required to receive type approval, are also subject to random testing designed to carry out the conformity inspection. Because other cities are behind Beijing in terms of vehicle emissions standards, cars originally registered outside Beijing must meet Beijing's emissions standards before they can be re-registered (for example, as a result of change in ownership) in Beijing. Green environmental marks are granted to those new vehicles complying with the new emission standards, which were implemented on January 1, 1999, and to vehicles already in use that comply with the new emission standards after renovation. Vehicles with the green environmental marks can enjoy exemption from road tests and random testing, and won't be restricted on the road when there is an air pollution alarm.

## **4 Emission control for vehicles in use**

### **4.1 Methods for testing vehicle emissions**

Methods for testing vehicle emissions depend on the type of emissions regulations the particular vehicle is subject to. The stricter the requirement for vehicle emission regulation, the more closed the test methods' driving cycle must be compared to a real driving cycle. In Beijing, the dual idle speed method is the current vehicle testing method, and the simplified driving cycle method will be brought into use from 2003.

#### **4.1.1 The dual idle speed method<sup>[7]</sup>**

Testing of vehicles already in use distinguishes between vehicles using gasoline and those using diesel. In China, idle speed testing (GB/T 3845-93) is basically adopted by most vehicles testing stations, but dual idle speed testing (DB11/044-1999) is adopted by all vehicle testing stations in Beijing, i.e., the testing will check vehicle emissions at two speeds: idle speed and high idle speed (2000 r/min). Though idle speed and dual idle speed-testing methods cannot really reflect the vehicles' real running condition, the two testing methods are widely used because they can be easily manipulated, are fast, and have low costs. Table 6 below shows the degree to which the various inspection tests are able to measure emissions from various types of vehicles.



**Table 6. Percent of vehicle emissions captured by different emissions tests <sup>[8]</sup>**

	Dual idle speed	High idle speed	Idle speed
All vehicles	100%	76%	83%
Passenger car	100%	88%	75%
Light Duty Vehicles I	100%	60%	92%
Light Duty Vehicles II	100%	75%	86%
Jeep	100%	77%	85%
Heavy Duty Vehicles	100%	76%	71%

Table 6 shows that, while the dual-idle speed method can capture the total emissions from each vehicle type, the other two methods miss some of the emissions. Thus compared to dual idle speeds, using a single idle speed to check the vehicles cannot guarantee that the vehicle meets emissions standards, which also means that these vehicles cannot be controlled effectively in the following period. To ensure that vehicles meet Beijing's current standards, then, it is reasonable and necessary to adopt the dual idle speeds testing method for checking vehicle exhaust pollutants.

#### **4.1.2 The simplified driving cycle method <sup>[9]</sup>**

The simplified driving cycle method is the simplification of the driving cycle method, which is a test that uses a dynamometer to test how the vehicle operates on a predefined driving cycle curve, thus simulating the vehicle's road performance. This method can simulate the vehicle's acceleration, deceleration and cruising by loading or unloading the vehicles. The driving cycle test can check the working condition of each part of the vehicle and can supervise and control the exhaust emission condition by adding emissions detecting equipment.

The precision of the simplified driving cycle method differs somewhat from the loading and unloading of vehicles in the driving cycle method. Other differences include the following: the mechanical ports are subjected to less strict environmental standards; the driving cycle is derived from the whole driving cycle curve; the running process is relatively simple; it is less time-consuming; and it is adapted to inspecting large-scale vehicles. In Beijing, the driving cycle method depends on "Beijing Gasoline Vehicles Steady-state Loading and Unloading Pollutants Exhaust Standard DB11/DXX-2000 (recommended)" <sup>[10]</sup>.

Because the driving cycle method can accurately simulate the vehicle's running exhaust condition on the road, it is better equipped than the idle speed testing method to detect whether or not vehicles meet environmental standards. If the driving cycle testing method is assumed to be exact, then we can calculate the commission rate (the percentage of vehicles measured to fail emissions standards) and omission rate (the percent of emissions not captured by the test) of idle speed method relative to driving cycle method. The results are illustrated in table 7.

**Table 7. The accuracy of the idle speed test compared to the driving cycle method <sup>[11]</sup>**

Vehicle test categories	Carburetor vehicles	Renovated carburetor vehicles	EPI vehicles
Number of vehicles tested	66	39	50
Number of vehicles that did not meet emissions standards according to the idle test	28	17	14
Number of vehicles that did not meet emissions standards according to the driving cycle test	33	13	21
Number of vehicles that failed both the idle test and driving cycle test	12	8	6
Commission rate	24%	23%	16%
Omission rate	32%	13%	30%
The sum of commission rate and omission rate of idle test	56%	36%	46%

In table 7, the assumption is that the driving cycle test method is 100% correct. Relative to driving cycle test method, the sum of the commission rate and the omission rate of idle test is quite high, its average value ranging from 40% to 50%. Thus the driving cycle for testing exhaust emissions has some clear advantages over the idle speed method. So, we proposed that the driving cycle method should be used as much as possible in developed areas in China, especially in Beijing.

## **4.2 Vehicle inspection/maintenance (I/M) and results in Beijing**

Implementing inspection and maintenance (I/M) system is the main measure for controlling vehicle emissions and its results will reflect the vehicles' control level.

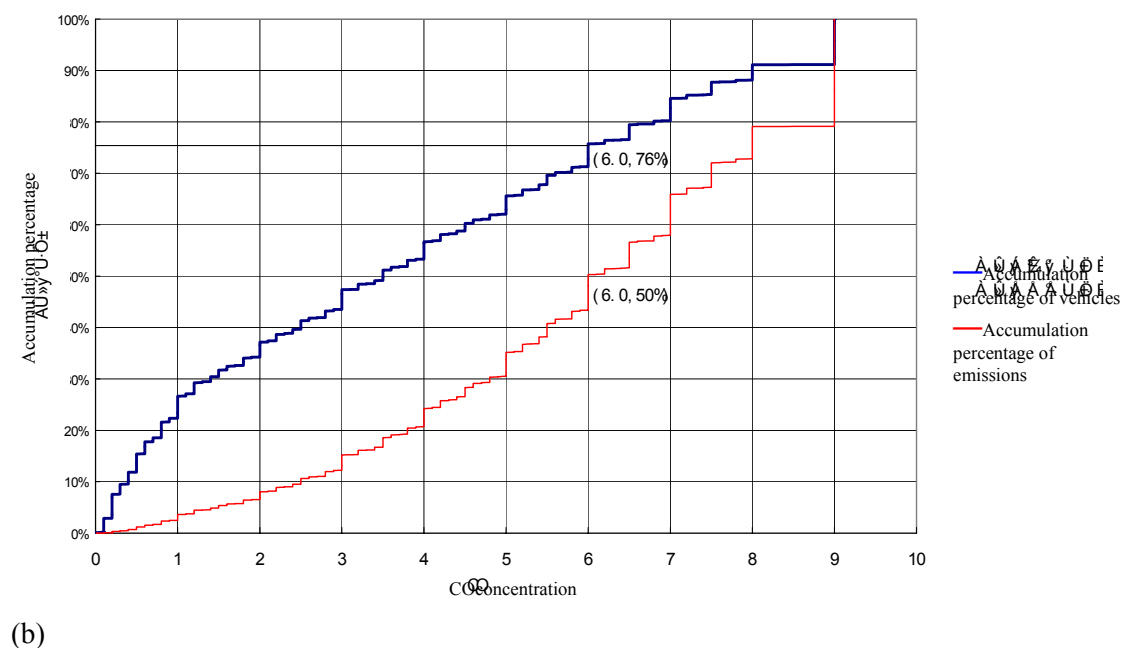
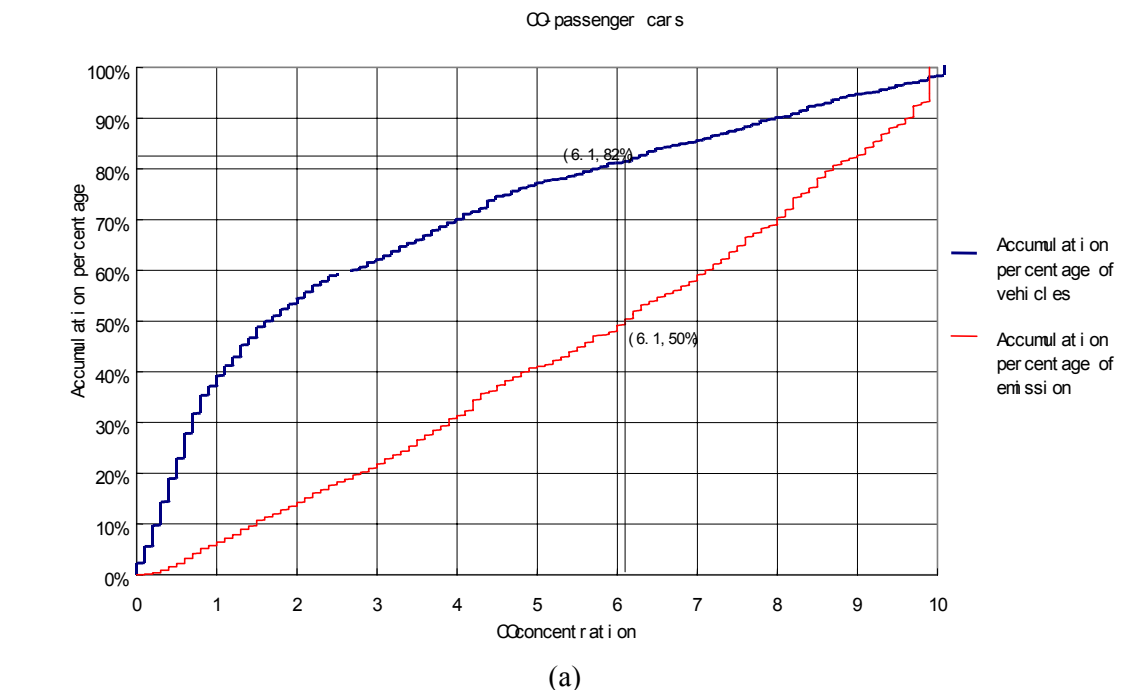
### **4.2.1 The inspection of vehicles**

The inspection of vehicles includes annual inspection, roadside inspection, random tests in parking lots, and vehicle inspections for cars entering Beijing. Annual inspection and roadside inspection are the main parts of inspection.

The idle test CO curves of accumulative percentages on passenger cars in Beijing are shown in Figure 2. Figure 2 (a) shows the annual inspection data and (b) shows roadside inspection data.

“Accumulation percentage of vehicles” refers to the percentage that the number of vehicles less than certain concentration accounts for one type of vehicles. Figure 2 show that the annual inspection data clearly shows greater adherence to environmental standards than roadside inspection data. In Beijing, because the analytical instruments used in the various types of inspections are the same, i.e., without system error, this discrepancy in results reflects the fraudulent practices of drivers. In other words, some drivers adjust their automobiles to better controlling level before the annual inspection and readjust back to original state after annual inspection. Thus, the results of roadside inspection more closely resemble real vehicle emissions level than annual inspection. Moreover, a car that is not in compliance with environmental standards in an annual inspection will not be permitted to be driven on the

road; and cars that are not found to be compliant in roadside inspections, will have their plates temporarily confiscated by the traffic administration department.



**Figure 2. Idle test CO curve of accumulative percentages for passenger car from (a) annual inspection data, and (b) roadside inspection data**

#### 4.2.2 Vehicle maintenance

Vehicles that do not meet current standards must be upgraded before they may be driven on the road. These vehicles may be repaired in the maintenance stations set up by automobile manufacturers and maintenance enterprises administered by the department of maintenance management. In other words, those manufacturers that sell automobiles in Beijing have to

build their maintenance stations to carry out maintenance services. Furthermore, all maintenance enterprises that are responsible for auto emission treatment must be equipped with a tailpipe exhaust analyzer for checking tail gas free of charge.

### **4.3 Upgrading in-use vehicles**

In order to further reduce serious vehicle emission pollution in Beijing, great efforts were made to upgrade in-use vehicles. The emphasis involves the renovation of traditional gasoline and diesel vehicles and the development of gas-fueled vehicles.

#### **4.3.1 Renovation of traditional gasoline and diesel vehicles**

##### **Electric control air replenishing + TWC**

In 1999, Beijing implemented technical renovation of closed-loop, electronic fuel injection or electric control air replenishing plus three-way converter (TWC) for light vehicles registered after 1995. The statistics of implemented status show that nearly 120,000 vehicles had been renovated by the end of 1999. It is estimated the total number for renovation is 150,000.

Using data from 31,718 vehicles obtained December 1999, a further analysis of the dual idle speed exhaust test result of renovated vehicles results in the following tentative conclusions:

The results of the idle speed test before and after renovation show a clear improvement. Comparing the idle speed exhaust of an in-use vehicle before and after renovation shows a decrease rate of exhaust density at low idle speed of CO: 97.8%; HC: 89.1%; at high idle speed: CO: 97.1%; HC: 89.5%.

- The decrease in single vehicle exhaust before and after renovation is clear. The working mode test results of some of the vehicles before and after renovation show that the single vehicle exhaust factor decrease rate of vehicle in use is CO: 78-90%; HC+NOx: 71-88%.

##### **Fuel efficiency**

Since renovated vehicles require the engine-working point to approximate the theoretical air-fuel ratio, the fuel consumption of renovated vehicles is usually increased and thus the fuel efficiency decreases. According to the results of a multiple working mode test, the fuel consumption of Red Flag and Citroen increased by 7.8% and 5.1% respectively, and that of Santana decreased slightly (-4%). After renovation, the dynamic feature change of the above vehicle models is normal, so that the renovation does not greatly affect the application performance under normal application conditions.

As a tentative estimation and taking the deterioration factors under consideration, the decrease effect of this renovation technology is sampled as: CO, HC-80%; NOx-70%; the service life is two years or 50,000 km. Given this data, renovation of 150,000 vehicles can reduce annual emissions of pollutants by the following amounts:

CO: 120,000t/year; HC: 18,000t/year; NOx: 6400t/year

It can be seen that after renovation of these vehicles, pollutant exhaust can be decreased to some extent. Compared with the total exhaust pollutants amount of the vehicles of the whole city, the decrease rate is 5-8%. Since the renovation vehicles are mostly saloon cars (sedans), their NOx exhaust factor is small so that the decrease proportion of NOx is less than CO and HC. Given the vehicle pollution sharing rate in Beijing and the fact that saloon cars occupy a larger proportion of the vehicles running in the urban area, it can be calculated roughly that the air quality improvement rate of NOx is around 7%, and the air quality improvement rate of CO is around 8-9%. On the two sides of the communication lines and during non-heating seasons, the improvement rate for air quality is higher.

### Vacuum Time Delay Valve

Another renovation measure in Beijing with large coverage range is to install a vacuum timing valve in in-use vehicles manufactured before 1995. As a tentative estimation, assuming the decrease rate of this measure for NO<sub>x</sub> is 10%, and a total of 400,000 vehicles are to be renovated; the result can be analyzed as below:

NO<sub>x</sub> decrease amount: 4,000t/year; NO<sub>x</sub> air quality improvement rate 5%.

The above calculation and analysis are based on the precondition that each technical measure works normally with a completed quality guarantee system. Vehicles with a vacuum timing valve should be inspected and maintained regularly in order to discover malfunctions in the engine and its exhaust control device so as to keep proper exhaust decrease effect.

### 4.3.2 Development of natural gas-fueled vehicles in Beijing

With the impending strict environmental regulations and continuous improvement in technologies, gas-fueled vehicles have developed to the 3rd generation technology.

#### (1) 1st generation gas-fueled vehicles

The 1st generation vehicles use a mechanical mixing chamber that has the same disadvantages as the traditional carburetor automobiles: the distribution of strokes is not uniform, and the regulatory precision not accurate. The 1st generation is the primary stage of developing vehicles, and has improved results for vehicle exhaust pollution compared to gasoline vehicles, but the power loss is greater. And the 1st generation vehicles do not meet the Euro I standard yet. The detail pollutant reduction results for 1st generation vehicles are shown in table 8.

**Table 8. Development of natural gas-fueled vehicles: 3 Generations<sup>[12]</sup>**

Items	Vehicle categories	CO REDUCTION (%)	HC REDUCTION (%)	NO <sub>x</sub> REDUCTION (%)	POWER LOSS (%)
1 <sup>ST</sup> GENERATION	LPG VEHICLES	50–60	40–50	0–10	2–5
	CNG VEHICLES	60–70	50–60	20–30	15–20
2 <sup>ND</sup> GENERATION	LPG VEHICLES	75–85	75–85	70–80	1–4
	CNG VEHICLES	80–90	80–90	75–85	5–15
3 <sup>RD</sup> GENERATION	LPG VEHICLES	85–95	85–95	80–90	0
	CNG VEHICLES	90–99	90–99	85–95	0

#### (2) 2nd generation gas-fueled vehicles

Characteristic of 2nd generation gas-fueled vehicles is that they use an electronic control-mixing chamber, their controlling precision is higher than 1st generation vehicles, and there are equipped with closed loop control and TWC equipment. Of these 2<sup>nd</sup> generation vehicles, some are dual-fueled alteration vehicles and the others are dedicated vehicles. The capability of the 2nd generation gas-fueled vehicles is improved further, and their power capability is improved slightly. The 2nd generation vehicles can meet the Euro II standards. The detail pollutants reduction results for 2nd generation vehicles are illustrated in table 8.

### (3) 3rd generation gas-fueled vehicles

Characteristic of 3rd generation gas-fueled vehicles is that they adopt electronic injection (EPI), matching closed loop control and dedicated TWC equipment, almost all are dedicated gas-fueled vehicles, and new vehicles occupy rather high percentage. This kind of vehicle can meet Euro III, Euro IV and super low-emission vehicle standards of California. Their power capability is close to that of gasoline and diesel vehicles. The detail pollutant reduction results for 3rd generation vehicles are illustrated in table 8.

All in all, the 1st and 2nd generation vehicles are transitional, especially the 1st generation technology, in the sense that these common carburetor gasoline vehicles are directly altered to dual-fueled vehicles in a makeshift manner. Overseas manufacturers at large currently adopt the 3rd generation technology, and dedicated gas-fueled vehicles are being developed.

### (4) Pushing gas-fueled vehicles based on Beijing's local conditions

At present, the gas-fueled vehicles are most commonly altered type of in-use vehicle, and the technology level lies in the 1st period.

Vehicles that use CNG or LPG by the reasonable system matching not only emit less HC and CO than the same level technology gasoline vehicles that are not equipped with an exhaust cleaning system, but also the fuel expense is slightly lower (depending on local natural gas prices). Accordingly, different areas in China can create incentives to upgrade alternative fuel vehicles. Because carburetor vehicles are the most common type of vehicle throughout China, and the new regulations only aim at new vehicles, this means that even though the 1st generation gas-fueled cannot meet Euro I standards, we have to push to adopt dual-fuel vehicles system in order to reduce the in-use carburetor vehicles' emissions.

Compared to gasoline and diesel vehicles, gas-fueled vehicles have excellent emission performance. Based the consideration of environmental protection and optimizing the energy configuration, CNG and LPG are regarded as the most alternative fuels in the 21st century. Table 9 shows that the estimation of NO<sub>x</sub> reduction for renovated LPG, CNG and other kinds of vehicles in Beijing.

**Table 9 The estimation of NO<sub>x</sub> reduction for renovated LPG and CNG vehicles in Beijing<sup>[13]</sup>**

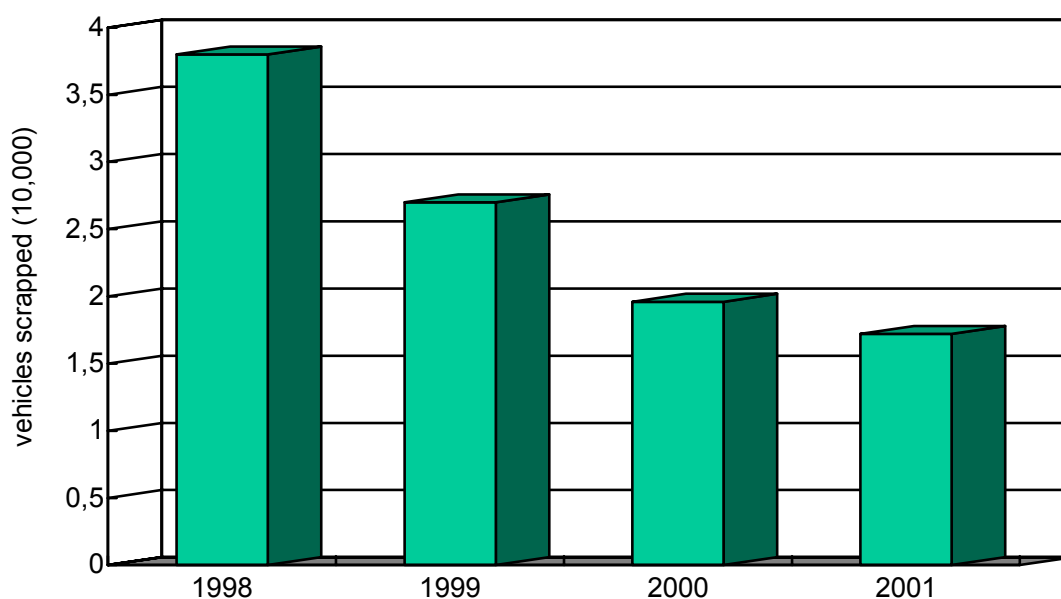
ITEMS		Public buses	Taxi	Mini buses	Envir. Sanitation vehicles	Postal use Vehicles	Specialty Freight Vehicles	Official Vehicles	TOTAL
<b>year 2000</b>									
LPG	Vehicles' number	1700	20000	2000	200	500		5000	29400
	Reduction(t/y)	173.4	450	125.0	32.9	16.0		12.5	805.7
CNG	Vehicles' number	2300			300	1000	2000	10000	15600
	Reduction(t/y)	1171.3			246.4	160.0	267.5	125.0	1970.2
Total Reduction(t/y)		1344.7	450	125.0	279.3	176.0	267.5	137.5	2780.0
Concentration Lessen (µg/m <sup>3</sup> )									1.7
<b>year 2002</b>									
LPG	Vehicles' number	1900	60000	4000	400	1000		5000	72300
	Reduction(t/y)	478.7	13830.8	2000.0	525.7	256.0		12.5	17103.7
CNG	Vehicles' number	3500	5000		1000	1500	10000	25000	46000

	Reduction(t/y)	3126.9	1784.6		2086.4	416.0	3691.5	725.0	11830.4
Total Reduction(t/y)		3605.8	15619.2	2000.0	2612.1	672.0	3691.5	737.5	28938.2
Concentration Lessen ( $\mu\text{g}/\text{m}^3$ )									17.9

#### 4.4 Enforcement of regulations governing scrapping of vehicles

With the accumulation of driving distance, vehicle emission performance deteriorates linearly, having an increasingly detrimental impact on air quality. At present, heavily polluting in-use vehicles already out of their service life account for 20% of the vehicle fleet while emitting 50% of total vehicle emitted CO and HC. Therefore, enforced scrapping must be conducted over those heavily polluting vehicles already exceeding their driving distance limit or service life. By 2002, the scrapping of the existing 600,000 in-use vehicles manufactured before 1992 will be completed. In addition, incentives to encourage replacement of vehicles still in their service life can be considered to improve the overall quality and technical level of the vehicle fleet.

Elimination of old vehicles from Beijing includes three aspects: transferring the vehicles to areas outside Beijing, stopping the vehicles from driving, and scrapping. Figure 3 shows the volume of old vehicles scrapped from 1998 to 2001.



**Figure 3. The volume of old vehicles scrapped from 1998 to 2001**

From Figure 3, we can see that the volume of old vehicles scrapped decreases gradually from 1998 to 2001.

All in all, with stricter emissions control of both new and in-use vehicles, the NO<sub>x</sub> concentration began to decrease in 1999 and became stable from 2000, though the vehicle population in Beijing is growing significantly. The situation is illustrated in Figure 4.

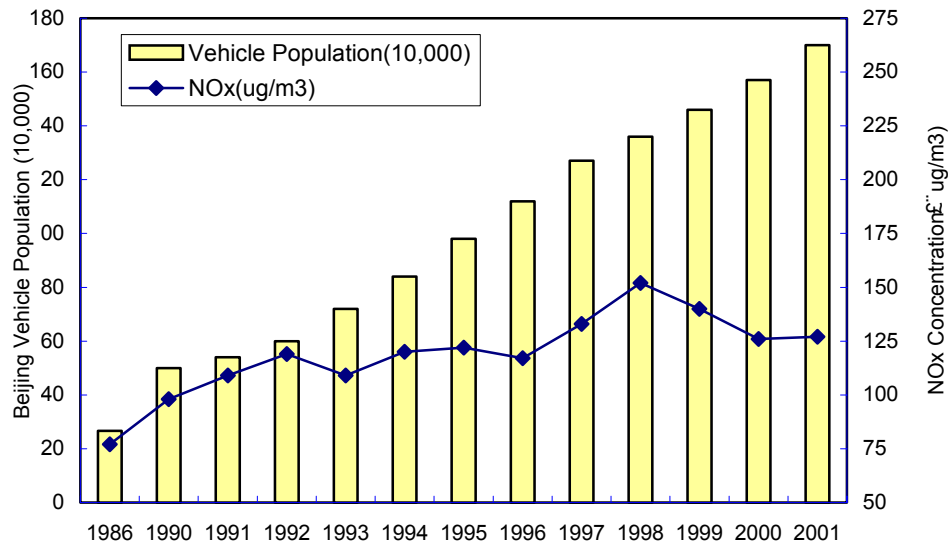


Figure 4. NOx in Beijing ambient atmosphere

## 5 Road infrastructure and traffic policy

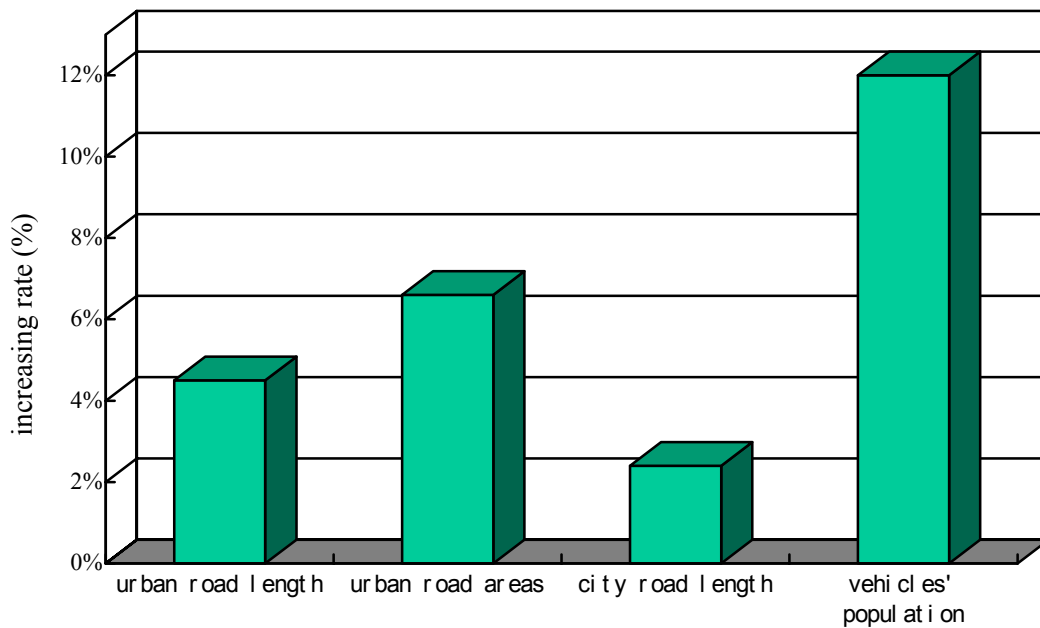
Since the mid 1980s, an increasing vehicle fleet in the urban area has meant that traffic congestion is becoming more and more serious. With the continuous increase in vehicle flow density on the traffic road in the urban area, pollutants emitted by vehicle are increasing greatly, especially NOx and CO. This implies that we must pay great concern to traffic and environmental issues in Beijing and find a way to solve the existing problems.

### 5.1 Traffic and environmental issues in Beijing

Traffic and environmental issues in Beijing lie in the following aspects:

First, traffic congestion is caused by deficient road infrastructure, particularly broken road capacity balance and structure balance as well as defects in land utilization structure. The increasing inability of the road network to meet traffic demands, the high percentage of broken roads among the lengths of trunk road, secondary trunk roads, and branch roads, and the spatial distribution defects of the road network results in serious traffic issues, which is reflected in the continual increases in vehicle flow density on urban trunk roads and in vehicle flow at intersections. From 1994 to 1997, the per kilometer lane vehicle load rose from 700 to 918; during peak hours, the number of high flow intersections (vehicle flow exceeding 10,000 per hour) increased from 29 to 45. Figure 5 shows the comparison of the road situation to vehicle increase during the “9th five-year” period in Beijing. Currently, the situation in Beijing is even more serious.





**Figure 5. Comparison of the road situation to vehicle increase during the “9th five-year” period in Beijing**

Secondly, radial traffic with the urban area as the center occupies a dominant position in Beijing's traffic structure, which aggravates the intensive traffic situation. Currently, the traffic load entering and leaving the urban area accounts for 27.8% of the total traffic population in the city. Vehicle flow generation and attracting intensity in the urban area is 5.1 times that in the suburb, which turns the urban area into high traffic density. The more important reason is the urban area is over-populated and over-constructed despite deregulation in land utilization structure adjustment.

Thirdly, even though investment in traffic facilities has been increased in recent years, the overall average driving speed is decreasing, especially the performance of public buses and trolley buses. During peak hours, bus speed on some bus line is even close to walking speed. Bus punctuality decreased from 70% in 1990 to 8.4% in 1996. Traffic congestion has resulted in reducing of over 1,000 bus tour per day. In 1997, special bus lanes were developed on some traffic trunk lines, leading to an increase in bus speed and certain improvements in public passenger transport.

Finally, the concentration of air pollutants in the traffic environment shows a gradient distribution from the urban area to the outer area. Annual average CO and NOx concentrations in the atmosphere within the Second Ring Road are 15% and 24% higher than those between the Second Ring Road and the Third Ring Road. The direct cause of this phenomenon is the high vehicle flow density on the urban road and serious traffic congestion, which means that vehicles operate at idle speed for longer periods, they move at slow speeds, they accelerate and decelerate quickly, etc. Furthermore, at these driving modes, they will emit more NOx, HC and CO than under stable operation. Therefore, it's clear that vehicle emission is not only affected by the number, quality and technical level of vehicle fleet, but also closely related with urban transportation conditions.

## **5.2 Improvement in road infrastructure and traffic policy**

Moderate total transport population and a relatively balanced distribution of traffic flow will be realized through rationalizing land utilization structure and land development intensity. Uncontrolled development and intensified concentration of high volume building as well as land development progress in the urban area will be brought into strict control. Traffic

impact assessment is required for developing of all types of new large size public buildings to prevent increasing over-intensified traffic sources. This is an important approach to keep moderate traffic environment and prevent traffic congestion from the source.

Based on the population, resource and productivity development level, a bus rapid transit (BRT) system should play a dominant role in urban transport system of metropolitan Beijing. The long-term target is to establish an above-ground and underground rail system. In the short term, focus is put on development of public buses and trolley buses to serve the passengers and tackle traffic pollution. Rapid rail transportation has been proven to be the best solution for urban transport. In developed countries, rapid rail systems carry 50%-80% of transport volume. However in Beijing, rail systems carried only 11% of the total public passengers transport volume in 1999. Although we have invested heavily in rail transportation in recent years, Beijing still falls behind the developed countries. As an advanced rail transport system is costly and requires a long construction period, it cannot be taken as immediate solution. Moreover, as a traffic trunk system in the urban transport system, a rapid rail system also requires ground trunk and branch public bus and trolley bus route as support. Therefore, development of public buses can serve both the immediate and the long-term demands. Beijing's situation of development of public buses and trolley buses in 1998, 2000 and 2001 is illustrated in table 10.

year	vehicle number	running lines (route)	route length (km)	special lane for buses (km)	carrying passengers per year (100million)	average carrying passengers per day ( $10^4$ /d)
1998	5400	320	6170	10	32	877
2000	9970	420	9276	33	38	1041
2001	11580	461	11072	147.2	38.8	1062

**Table 10. The development of public buses and trolley buses in Beijing**

Efforts are being made to raise the driving speed of vehicles so as to reduce the vehicle emission factor (the emission amounts for vehicles driving one kilometer g/km). In 1999, the main policy was to build a rapid road system, i.e., the function division of the existing road network and lane traffic load are under adjustment, there are plans to set up the two roads and ten connection trunk roads as the framework, and 22 secondary trunk roads and branch roads were under renovation to eliminate the interference between local traffic and passing traffic on the urban road network and allow the roads of different function in the urban area play their respective role. Even now, the fifth and sixth ring roads, urban track system and some trunk and secondary trunk roads are under construction. When the three-dimensional transportation system is basically finished, the second and third ring during peak hours are expected to reach 45 km/h and 50 km/h respectively and driving speed on the main connection trunk roads are expected to reach 30 km/h.

Steps are being taken to not only construct an improved urban transportation system, but also to manage the transportation system. Management should depend on science and use road source fully, i.e., to develop intellectual transportation system. The hands of policemen should not control the traffic lights, which depend on traffic flow and temporal distribution;

thus, the traffic lights should be automatic. Moreover, a tax on traffic pollution is under consideration. On the one hand, levying pollution charges can encourage emissions control for in-use vehicles and speed up scrapping of old vehicles; on the other hand, it can collect funds for controlling traffic pollution.

## 6 Conclusions

Along with the improvement in vehicle technical levels, especially emissions control technology, stricter requirement are being considered for fuel quality. The quality of existing fuel already falls behind the requirement of vehicles with a high technical level, and has become one of the factors affecting emissions. The petroleum products in China do not meet the new regulation requirements in many aspects; thus, we must consider the improving process of Chinese industry when we establish the implementation timetable of new emission regulations.

Stricter vehicle emissions standards are issued and are being implemented in steps. This is an effective measure for reducing emissions from new sources. Green environmental marks are granted to those new vehicles complying with the new emission standards, which were implemented on January 1, 1999, and the in-use vehicles complying with the new emission standards after renovation. Vehicles with the green environmental marks can enjoy exemption from road tests and random testing, and won't be restricted on the road when there is an air pollution alarm.

The enforcement of in-use vehicle emissions control is carried out in six ways. (1) With the driving cycle test method, the sum of fault-inspection rate and missing-inspection rate of idle test is quite high, its average value ranging from 40% to 50%. The driving cycle for testing exhaust emission has some advantages over the idle method. We thus proposed that the driving cycle method should be used as much as possible for those developed areas in China, especially in Beijing. (2) A car that is not in compliance with environmental standards in an annual inspection will not be permitted to be driven on the road; and cars that are not found to be compliant in roadside inspections, will have their plates temporarily confiscated by the traffic administration department. (3) All vehicles failing to meet the emission standards in various tests are required to conduct treatment by installing matching emission purification facility, and will be allowed to be on the road only after complying with the emission standards. (4) The renovation of traditional gasoline and diesel vehicles: electric control air replenishing + TWC and vacuum time delay valve. (5) Compared to gasoline and diesel vehicles, gas-fueled vehicles have excellent emissions performance. Based the consideration of environmental protection and optimizing the energy configuration, CNG and LPG are regarded as the most promising alternative fuels in the 21st century. (6) Enforcement of vehicle scrapping regulations. Forced scrapping must be enforced for those heavy polluting vehicles already exceeding their driving distance limit or service life.

With respect to the construction and management of the transportation system, efforts will be focused on regulating urban transport demands, adjusting urban road networks and transport structures, improving transport operation conditions, formulating and enforcing gradually stricter regulation and standards. The necessary technical and economic approaches will be adopted to control vehicle emissions. The overall objective is to reduce vehicle emission by steps for improvement of atmosphere environment in Beijing while the overall transport population keeps increasing.

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